Journal of Environmental Science and Technology

ISSN 1994-7887

science alert

ANSInet
an open access publisher
http://ansinet.com

OPEN ACCESS Journal of Environmental Science and Technology

ISSN 1994-7887
DOI: 10.3923/jest.2017.88.95

Researcher Article
Study of Depth Control Method for Unmanned Underwater Vehicle (UUV)

[1,2]Syed Faiz Ahmed, [2]Hazry Desa and [2]Abadal Salam Taha Hussain

[1]British Malaysian Institute, Universiti Kuala Lumpur, Malaysia
[2]Center of Excellence Unmanned Aerial System, University Malaysia Perlis, Malaysia

Abstract
Background and Objective: Appropriate depth controlling in Unmanned Underwater Vehicle (UUV) are always the challenging part. Several researches developed techniques to make smooth depth controlling in UUV but still there is a lot of room of improvement in this area of research. The combination of non-linear behavior between both Unmanned Underwater Vehicle (UUV) and environment itself does the main problem on doing this optimal control method. While the Remotely Operated Vehicle (ROV) were controlled by human pilot which differs, there's a need to make this vehicle to make it autonomous to make the vehicle can move in autopilot mode. **Methodology:** In this study different depth controlling method of Unmanned Underwater Vehicle UUV were compared and perform analytical judgment on choosing the best depth controlling method for Unmanned Underwater Vehicle (UUV). **Results:** After the detail analysis of all selected depth control techniques, a performance analytical table was developed and analytical results showed that Hybrid Fuzzy PID control system was best suitable among the others control techniques. **Conclusion:** From this research study it was concluded that depth control is one of the critical factor in the performance of UUV and appropriate selection of depth control is very important. Proper choice of the controller definitely enhanced the performance of the UUV.

Key words: Bipedal, design, gait development, degree of freedom, servo motor

Received: January 02, 2017 Accepted: February 03, 2017 Published: February 15, 2017

Citation: Syed Faiz Ahmed, Hazry Desa and Abadal Salam Taha Hussain, 2017. Study of depth control method for unmanned underwater vehicle (UUV). J. Environ. Sci. Technol., 10: 88-95.

Corresponding Author: Syed Faiz Ahmed, British Malaysian Institute, Universiti Kuala Lumpur, Malaysia Tel: +60174610059

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The Unmanned Underwater Vehicle (UUV) has been recognized worldwide, there are people from military and commercial make this UUV as considerable research interest. They offer more features rather than ROV's in term of, Wide range movement (range and depth) and replace the function of human diver and expensive human submersible[1,2].

Different techniques of depth control method in UUV were explained in this study. As the title of this paper is study of depth controlling method of Unmanned Underwater Vehicle (UUV). Depth controlling of Unmanned Underwater Vehicle (UUV) is the most crucial part of UUV[3]. It's important for UUV operator, researcher or the buyer knows what exactly depth controlling need to be used to make the UUV worth its function. The shape of the UUV is also important in for controlling its depth. In recent year System and methods of using Unmanned Underwater Vehicles (UUVs) along with tethers and tethered devices is patented by an American researcher who explain the working of UUV in detail[4], in year 2015 another researcher explained the modeling of a complex-shaped Underwater Vehicle for its appropriate Controlling[5]. Before that in year 2013 one of the research group developed and modeled a low cost underwater Remotely Operated Vehicle (ROV) for depth control using system identification technique[6].

All these researcher and research group worked for the batter controlling of UUV and tried to find an optimal and suitable control method but there is still a lot of improvement can be done in this field of research. The main objective of this research study is to perform detail analysis of the available control techniques in the depth controlling for UUV and find an appropriate and best suitable method among the selected methods i.e., PID, Neural Network, Q-Sliding Mode Control and Fuzzy logic. This study will be helpful for other researches who are working in this domain of research.

MATERIALS AND METHODS

The UUV mathematical model is well build to test the efficiency of the control system. Computer Aided Design (CAD) such as TSIM and MATLAB are used to test and validate controller operating for the non-linear system and help to assist the engineer to test conceptual design before approve in real-time[7]. This only can be realizing if an accurate mathematical model are made before do any designing process for controller. This includes quantifying and modeling the result of aforementioned subsystem done in the following area[8]:

- Hydrostatics
- Hydrodynamics
- Rigid body coupling
- Thruster Dynamic
- Cross-coupling before the axes of freedom

These processes can be done by deriving the six freedoms of equations for an UUV by Daisley to three degree of freedom by Gorman. This equation is listed below:

$$\begin{aligned} m_2 v &= 0.5\rho A V_n^2 - m_1 pw - mh_z(qr - p) \\ J_x p &= 0.5\rho AdC_L V_n^2 + K_p p - wh_z \sin\theta + mhz(v - pw + ru) \\ J_z r &= 0.5\rho ALC_N V_n^2 - (J_y - J_x)pq \end{aligned} \quad (1)$$

There's a plenty parameter that will affect the non-linearity's and also string cross coupling influence between six degree of freedom which have to be considered to implement the mathematical model. For this study got the information from tow-tank tests undertaken by Marconi Underwater Systems Limited (MUSL) on a minnow WV and rejoice it with TSIM machine package. This endeavor is made to get linearized state space and transfer capacity representation however this was failed. Then, choose to achieve the definitive information utilizing standard mathematical statement recorded above with the Matlab Simulink workstation programming package. However, need to be expressed that it was conceivable to get exchange capacity shows dependent upon different working focuses. The UUV used in this study and recreation has four thruster which control the vertical and flat movement of the vehicle, two even thruster were utilized to have a steady yield of 10 Rotation per second (rps) and this will transform a consistent send velocity of 1.16 mds over ocean cot profile. Then, the vertical thruster produce indistinguishable yield to make the UUV move in straightforward vertical movement over topography. The thruster have an extent of working run off 20 rps., allowed a top speed 4 hitches ahead and 2 hitches a stern. taken from the exchange capacity 171 the relative integral-derivative (PID) controller was planned and the parameters acquired and achieve in this work. Figure 1 shows the square graph of the framework and controller.

Depth control using discrete quasi-sliding mode control: In this study utilize a Korean made UUV which name is VORAM (Vehicle for Ocean Research and Monitoring) and made by KRISO (Korea inquire about organization of Ships and Ocean building). Design and made for perception and examination of ocean bed, this study will concentrate on a discrete-time semi sliding mode controller with parameter lacks of determination and long inspecting interval. The controller are well-known for the framework steadiness in the vicinity of framework lacks of determination and outside noise. Depth bolt and shaping control are performed for a numerical model of the UUV with full non-straight comparisons of movement to approve the proficiency of the proposed control plans when long test interim are taken. To further this studies utilizing the discrete-time sliding mode control law, the UUV examination are finished on KRISO'S towing tank. For the introductory trial effect, the examination appears to be exact to the simulations, as example comes to be great, the viability of proposed control law is more.

Depth control using adaptive fuzzy logic depth: This study will exhibit to you an Adaptive Fuzzy logic Depth Controller lightness system (VBS) of an Unmanned Underwater Vehicle (UUV) this study will clarify to both of you sorts of soft controller which is Large Range Depth Controller (LRDC) and Small Range Depth Controller (SRDC). The soft control is about controlling delicacy to move the UUV in vertical development to a certain depth, by reducing and growing buoyancy, it will the UUV to move to the certain depth fuzzy guideline are arranged by the programmer and adaptively decipher the fundamental significance demonstrates for parity change needy upon a nexus parameter of the UUV dynamic model[9]. This study will advance cushy base for LRDC and present preparatory re-authorizations happens of the LRDC.

Depth control using application of improves hybrid PID control system: In this study, used hybrid fuzzy PID control system of a pump propelled autonomous underwater vehicle. Then, the subject used is U-Fish, a low UUV, First one propeller and consist of 4 pumps that mounted on the stern. The hybrid fuzzy PID control is use because the complexity to build the microcontroller system[10]. This controller type is model free and easy to realize and a wise choice for the complex system. To get the parameter-loop experiment must be done to which design the control law for horizontal plane and vertical plane. After do experiment, where the U-FISH travels at different heading angles and depth show that the complex system respond quickly and reaches satisfactory steady result in bot plane simultaneously. Upon the result, the feasibility of the control law is validated[11].

RESULTS

The increasing in development better propulsion and power storage have slightly increasing the UUV depth controlling method. Over a few year, the limitation of UUV is highly come from the depth controlling, this limitation prevent the UUV to perform a vertical ranged mission which is need a high accuracy in positioning. Since the costly grade Depth controlling system, Neural Networks, PID and Improves Hybrid PID can be used to degradation of navigation robust over the mission but their usage restricted due to the budget and range of UUV development. As matter of fact, the cheaper and more accurate control comes from Quasi-sliding Mode Control. In the other hand Adaptive Fuzzy Logic Depth comprise the cost effective and accuracy.

The analysis of several famous techniques with focusing on its open loop and close loop performance, the elevator angle and pith rate of UUV, sliding surface effect and also response of UUV under noisy condition are carried out in detail.

Analysis of Depth Control Using Neural network and PID Controller: The simulation trials show that neural networks proved to be an acceptable controller for the UUV modeled Besides, performance criterion provided an initial stern test and also meant that the neural network faces any other gradients could cope with improved performance than the results stated above, whereas the PID controller during the simulation perform well as neural network. Beside that neural network are proven to sensitive to noise and the surrounding, Table 1 shows the effect of different noises using PID control and Chemotaxis Network, the added noise is shown is Fig. 1, the effect of both Chemotaxis Network and PID controller on the UAV system is described in Fig. 2 and 3, respectively[12].

After applying both techniques i.e., PID control as well as Neural control on UUV system, the results are shown in Table 2, from which it can be easily observed that only PID controller had small success in trying to obtain its target.

Analysis of depth control using discrete quasi-sliding mode: The simulation trials show that this mode are also acceptable to be used as controller for UUV because it does have fast steady state error, stable elevation of UUV during the

Table 1: Results with noise on the system

Performance analysis	Chemotaxis network	PID controller
Mean squire error	2.692	32.039
Mean thruster revs	-1.723	-10.3032
S.D. revs	7.904	11.360

Table 2: Response of the controllers with both noise and change in mass place on the system

Performance analysis	Chemotaxis network	PID controller
Mean Squire error	3.7136	20.1760
Mean thruster rev	-1.6950	-0.6073
S.D. rev	8.1320	11.2530

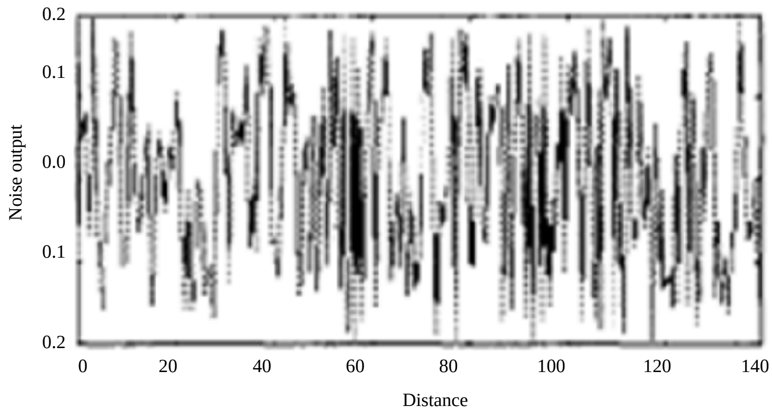

Fig. 1: Noise of the system

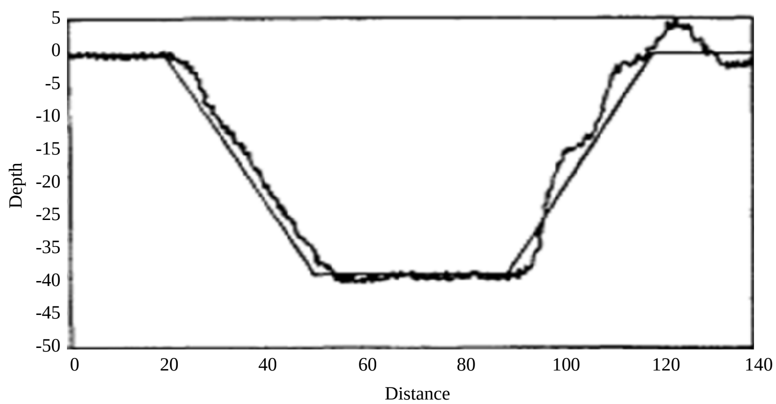

Fig. 2: PID controller with noise placed on the system

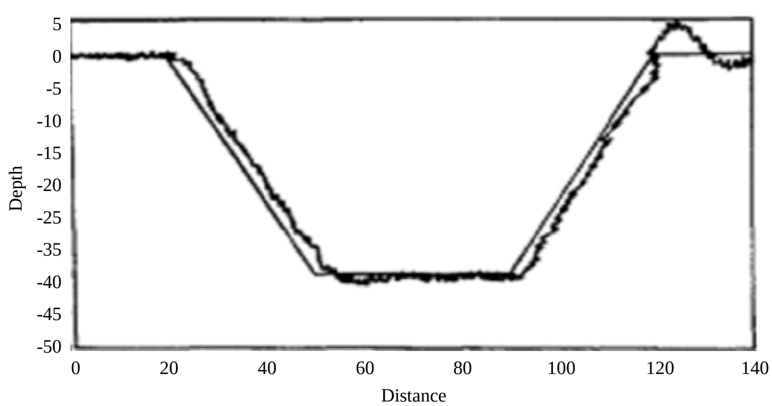

Fig. 3: Neural controller with noise placed on the system

controlled depth position and less sliding surface, Fig. 4 showing the effect of Discrete-time Sliding Mode Control on the system. The results of this study are has been shown in Fig. 5 which explain the experimental results of depth keeping control using Discrete-time Sliding Mode Control at $\Delta t = 0.5$ sec with $\rho = 0.8$, here solid line describing the experimental result, thick solid line is showing the calculated value and dash line is targeted depth. The experimental result with more less time i.e., $\Delta t = 2.0$ sec and $\rho = 0.3$ are shown in Fig. 6[13].

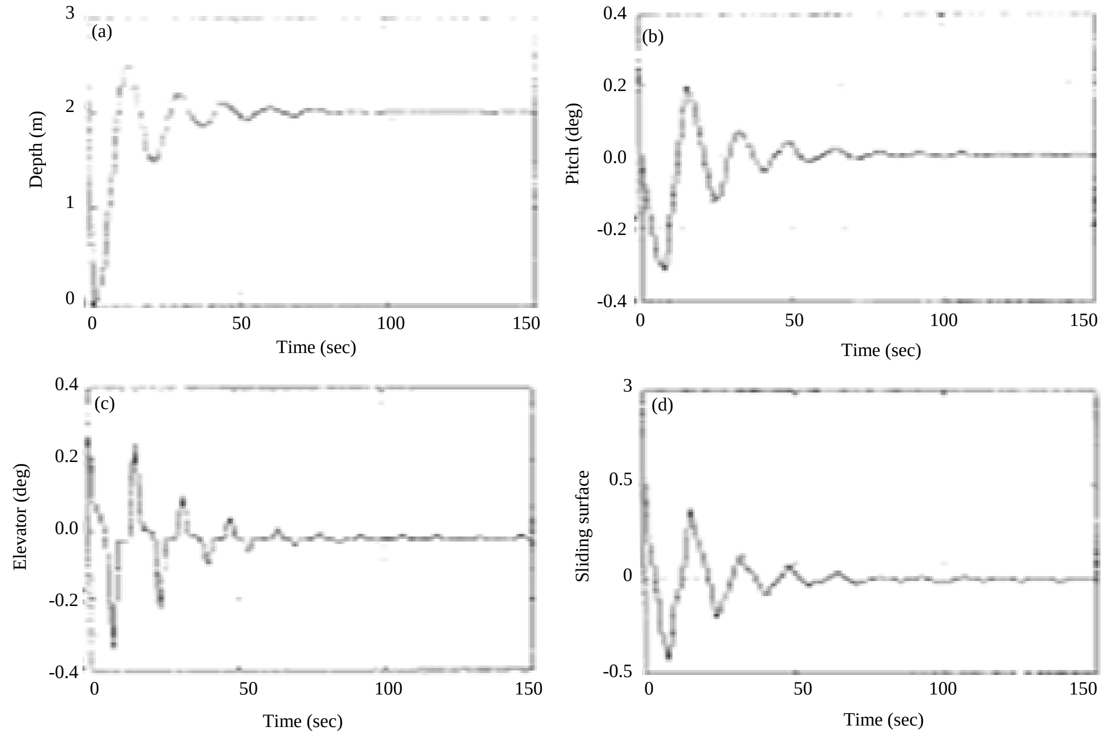

Fig. 4(a-d): Depth keeping control of VORAM with discrete-time sliding mode control
Δt = 2.0 sec, ρ = 0.3, F = {0.4, 0.4, 0.1}, D = [0.1, 0.0.1]

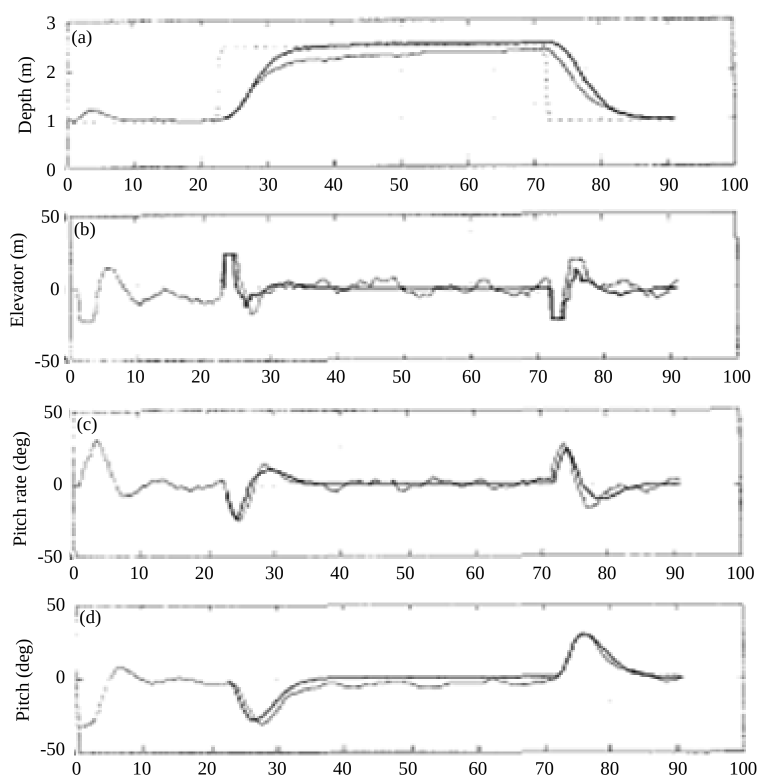

Fig. 5(a-d): Experimental results of depth keeping control with discrete SMG
Δt = 0.5 sec, ρ = 0.8; solid line-experiment, thick solid line-calculation, dash line-target depth

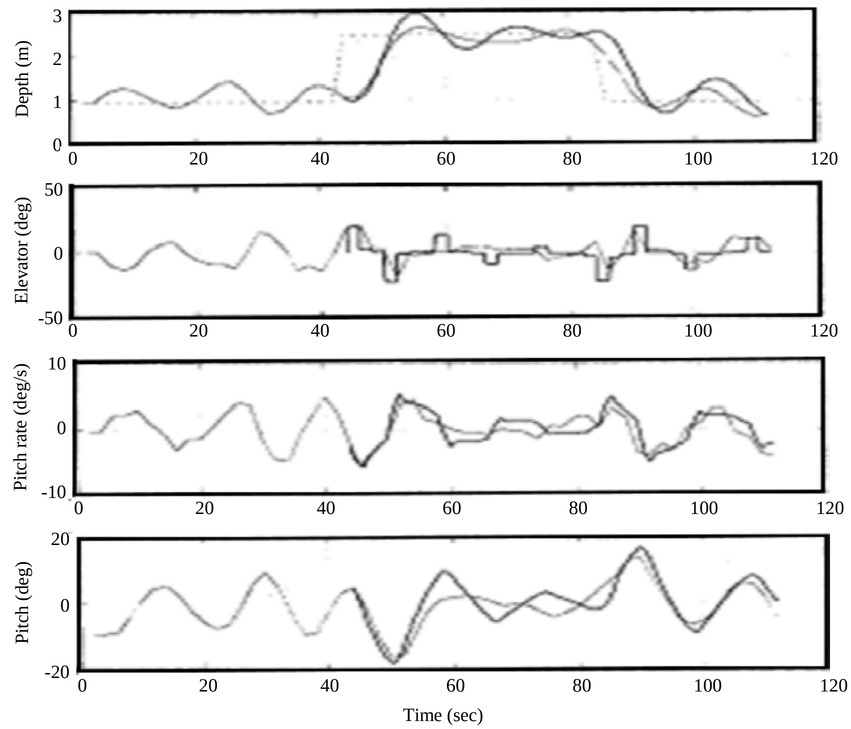

Fig. 6: Experiment results, $\Delta t = 2.0$ sec, $\rho = 0.3$

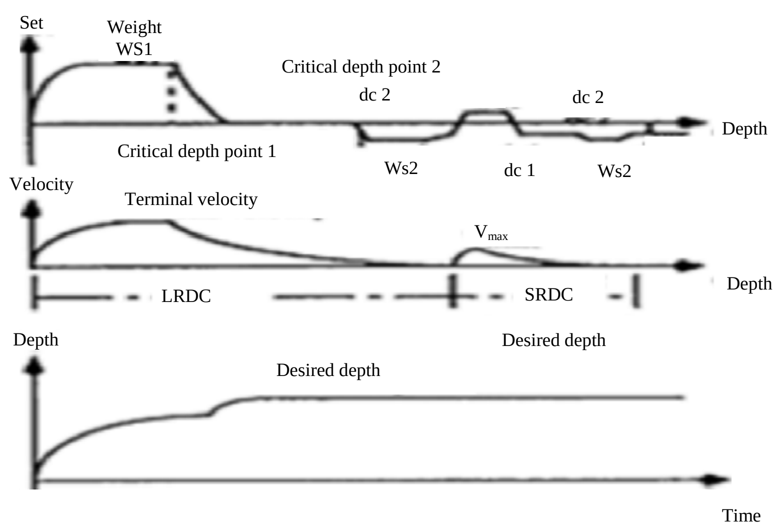

Fig. 7: Dynamic response of UUV/VBS

Analysis of depth control using adaptive fuzzy logic: Adaptive Fuzzy Logic are simple programming and yet suitable for Non-linearities behavior of UUV[14]. The dynamic response and its simulations result shows can be shown in Fig. 7 and 8, respectively

Analysis of depth control method using improves hybrid PID: This study has introduced the relationship between the exhibition of the vehicle and the calling cycles of the PWM signs sent to the pumps. Based upon this, it consolidate the fuzzy and PID strategies to outline a control law for the level plane and the vertical plane independently. At last, the nearby circle tests have ended up being phenomenal; both of the settling time and the enduring state failure are accomplish. The outcomes have demonstrated that this without model approach is adequate for the control of this modest ease vehicle.

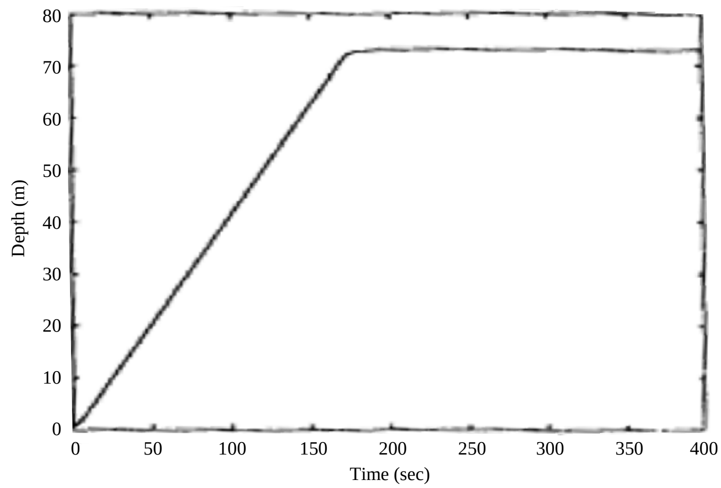

Fig. 8: The simulation results depth vs. system FCL

Table 3: Comparison base on features

	Controllers			
Features	Adaptive fuzzy logic depth	Quasi-sliding mode control	Neural network	Hybrid fuzzy PID control system
Open-loop performance	√			√
Closed-loop performance	√			√
Elevator angle			√	√
Sliding surfaces		√		
Response to noise	√		√	√
Pitch rate	√	√	√	√

After the detail analysis of all selected depth control techniques, a performance analytical table is developed as shown in Table 3 which describing the performance of these techniques.

DISCUSSION

For evaluating the effectiveness of depth control for unmanned under water vehicle system detail analysis had been done in results section and it is discovered that the hydride fuzzy PID control method for depth controlling is most suitable techniques in UUV applications.

The most common problem for Neural Network comes from the lack of sensitivity to performing on open and closed loop system[15]. The neural controller does not respond wisely to noise compare to hydride fuzzy PID control method. The range and offset angel also one of the factor of the error. Then, neural network has high sliding surface. On the other hand conventional PID control is also not recommended because of no adaptability and also not work in open loop condition[16].

The Discrete Quasi-Sliding mode control is suffer from a several error that come from the technique itself, the measurement are defined to the terrain sea-bed. The approach of the vehicle needs to be in a right situation to allow the sensor high precision condition. One of the disadvantages is come from the incompetence performance in the open and closed loop simulation and it error is inability to control the elevation angle. Focus on the data base map error, during the inertial mapping, the error come from the tide level results in a time varying vertical depth reference[17]. As the result the terrain map will defer from mean sea level- the inertial zero-depth reference line. This error is refer as depth bias, when using the discrete Quasi-Sliding technique for mapping the terrain, the vehicle sensor need to perpendicular to vertical normal line, so hydride fuzzy PID control is best it all above mention conditions respectively.

The typical problem of Adaptive Fuzzy Logic Depth system is the elevation angle is high[18], so when the vehicle is submerged, the signal will be not stable and the system has high sliding surface.

Among the others control method, Hybrid Fuzzy PID control system can be denoted as almost perfect control method to be used in UUV. The controller is only incompetence for one feature that is because it has high sliding surface.

CONCLUSION

This study presented analysis of different control techniques for Unmanned Underwater Vehicles (UUV) depth controlling and suggested an appropriate depth control method for UUV. The study revealed that the depth control is one of the important feature in UUV and optimal selection of the controller definitely improved the performance of the UUV. From the analysis and results of this study, it is concluded that suitable control techniques for depth controlling for UUV is Hybrid Fuzzy PID Control System among the selected one which worked well in all conditions.

SIGNIFICANT STATEMENT

This study described the significant of depth control for the performance of unmanned underwater vehicle (UUV). Different depth control techniques were presented and analyzed each of them and developed performance analytical table. It had been discovered that Hybrid Fuzzy PID control system was optimal control method among the selected methods.

ACKNOWLEDGMENT

This research had been done in Universiti Malaysia Perlis under the research cluster COEUAS, UNIMAP. We would like to acknowledge the effort and support of COEUAS management for development of this project and conducting this research work.

REFERENCES

1. Xu, M., 1992. Blowing of Variable Ballast (VB) tank and flooding of VB tank. FAU Technical Report.
2. Hazry, D., M.H. Tanveer, S.F. Ahmed, F.A. Warsi, M.K. Joyo and A.T. Hussain, 2014. Survey of conventional UUV navigation mapping technique in development of AQUA-X UUV. Artif. Life Robot. J., 1: 90-96.
3. Takagi, T. and M. Sugeno, 1983. Derivation of fuzzy control rules from human operator`s control actions. Proceedings of IFAC Symposium on Fuzzy Information, Knowledge Representation and Decision Analysis, July 19-21, Marseille, France, pp: 55-60.
4. Tang, R., 2016. System and methods of using Unmanned Underwater Vehicles (UUVs) along with tethers and tethered devices. U.S. Patent 9,440,718, September 13, 2016.
5. Yang, R., B. Clement, A. Mansour, M. Li and N. Wu, 2015. Modeling of a complex-shaped underwater vehicle for robust control scheme. J. Intelli. Robotic Syst., 80: 491-506.
6. Aras, M.S.M., S.S. Abdullah, M.Z.A. Rashid, A.A. Rahman and M.A.A. Aziz, 2013. Development and modeling of unmanned underwater remotely operated vehicle using system identification for depth control. J. Theor. Applied Inf. Technol., 56: 136-145.
7. Shein, A. and J. Kloske, 1991. Development of simulation facilities at Florida Atlantic University for AUV research. Proceedings of the SCCS, (SCCS'91), USA.
8. Cristi, R., F.A. Papoulias and A.J. Healey, 1990. Adaptive sliding mode control of autonomous underwater vehicles in the dive plane. IEEE J. Oceanic Eng., 15: 152-160.
9. Papoulias, F.A., R. Cristi, D. Marco and A.J. Healey, 1989. Modeling, sliding mode control design, and visual simulation of auv dive plane dynamic response. Proceedings of the 6th International Symposium on Unmanned Untethered Submersible Technology, June 12-14, 1989, IEEE., pp: 536-547.
10. Furuta, K., 1990. Sliding mode control of a discrete system. Syst. Control Lett., 14: 145-152.
11. Chan, C.Y., 1995. Robust discrete quasi-sliding mode tracking controller. Automatica, 31: 1509-1511.
12. Healey, A.J. and D. Lienard, 1993. Multivariable sliding mode control for autonomous diving and steering of unmanned underwater vehicles. IEEE J. Oceanic Eng., 18: 327-339.
13. Lea, R.K., R. Allen and S.L. Merry, 1999. A comparative study of control techniques for an underwater flight vehicle. Int. J. Syst. Sci., 30: 947-964.
14. Lee, P.M., S.W. Hong, Y.K. Lim, C.M. Lee, B.H. Jeon and J.W. Park, 1999. Discrete-time quasi-sliding mode control of an autonomous underwater vehicle. IEEE J. Oceanic Eng., 24: 388-395.
15. Fu, Y., Y. Liu, S. Liu, N. Wang and C. Wang, 2015. Design of Fuzzy-Neural-Network-Inherited Backstepping Control for Unmanned Underwater Vehicle. In: International Symposium on Neural Networks, Hu, X., Y. Xia, Y. Zhang and D. Zhao (Eds.). Springer International Publishing, Germany, pp: 109-118.
16. Abidin, A.Z., R. Mardiyanto and D. Purwanto, 2016. Implementation of PID controller for hold altitude control in underwater remotely operated vehicle. Proceedings of the International Seminar on Intelligent Technology and Its Applications, July 28-30, 2016, IEEE., pp: 665-670.
17. Azar, A.T. and Q. Zhu, 2015. Advances and Applications in Sliding Mode Control Systems. In: Studies in Computational Intelligence, Zhu, Q. (Ed.). Springer, Berlin.
18. Wang, Y., Y. Shen, K. Wang, Q. Sha, B. He and T. Yan, 2016. Fuzzy controller used smoothing function for depth control of autonomous underwater vehicle. Proceedings of the OCEANS, April 10-13, 2016, Shanghai, pp: 1-5.